ON THE INTENSITY VARIATIONS OF THE DOWN-COMING WIRELESS WAVES FROM THE IONOSPHERE*

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(Recived for Publication, June 19, 1940)

ABSTRACT. Experiments are described with an aerial system for suppressing the ground-wave. After having suppressed the ground-wave, the variations of the intensity of the down-coming wireless waves were studied. Typical continuous records of the variations of the intensity of such waves are presented. It has been shown that the time-variation of the amplitude of the down-coming waves is consistent with Rayleigh's formula for random scattering. The amplitude variation can therefore be explained as due to the interference of waves scattered from a series of diffracting centres at the ionosphere.

The most probable value of the amplitude of the down-coming wave as obtained from the experimental data on the intensity variations of the same wave was compared with the amplitude of the ground-wave Between Dacca and Calcutta, the ratio of the vertical electrical forces produced by the ground-wave and the down-coming wave was thus estimated.

I. INTRODUCTION

Appleton and Ratcliffe[1] had previously shown that in the case of reception of wireless signals on a wavelength of about 300 metres at a distance of about 130 km. the observed signal variations were due chiefly to variations in the intensity of the down-coming wave. They had also concluded that the variations in the phase relation between ground- and sky-waves were a secondary cause of fading and that changes in the angle of incidence or polarization of the down-coming waves were not responsible in any marked degree for signal variations. Working on wavelengths between 200 and 500 metres for distances of transmission less than 200 km. Ratcliffe and Pawsey [2] subsequently made a study of the intensity variations of the down-coming wireless waves. Considering the possible causes of intensity variations in the light of their experimental results, they suggested that a major cause of "fading" was the interference at the ground, of waves "scattered" from a series of diffracting centres distributed over some area in the ionosphere. In fact they observed lateral deviations of the wireless waves after reflections from the ionospheric layers. Further experi-

* Communicated by the Indian Physical Society.

ments by Pawsey[3] confirmed these conclusions. He showed that the time-variation of the amplitude of the reflected wave was consistent with the idea of random scattering at the ionosphere.

The object of the present investigation was to undertake a study of the variations of the intensity of the down-coming wave originally coming from the Calcutta V.U.C. station ($\lambda = 370.4$ m.) and received during the night hours at Dacca and to test whether the observed variations could be traced to similar random scattering at the ionosphere. For that purpose in view it was necessary to have the ground-wave suppressed.

RECEIVING SYSTEMS FOR THE ATMOSPHERIC WAVE

(*a*) Aerial system:

The aerial system used in this investigation was similar to that used by Ratcliffe and Pawsey[2]. The system was a combination of a vertical aerial with a triangular loop aerial with only two turns having its plane (which was vertical) lying in the direction joining the transmitter and the receiver (Calcutta and Dacca). The two aerials were coupled as shown in fig. 1 by way of a variable mutual inductance M between two suitable coils L_a and L_b, each one being in series with each of the two aerials. The two coils and the vertical aerial tuning condenser C_a were contained in a properly shielded box. The antenna effect in the loop was eliminated by arranging the loop circuit to be perfectly symmetrical and earthing the mid-point as shown in the figure.

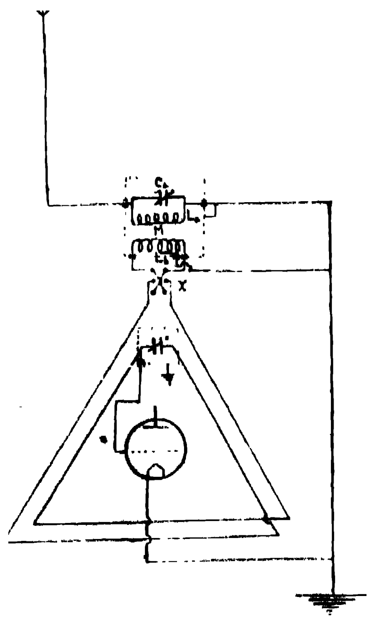

FIGURE 1

(*b*) The Receiver:

The receiving set which was of a regenerative type consisted of a H.F. amplifier, a detector and two L.F. amplifiers. (Fig. 2.) The regeneration was controlled by a variable condenser. A reflecting moving-coil galvanometer was placed in the anode circuit of the detector valve. With the help of a low tension battery and a variable resistance, the no-signal anode current through the galvanometer was balanced out. After suitable adjustments (to be described subsequently) of the suppressed-ground-wave aerial system and carefully tuning the set and adjusting its reaction condenser, the deflections produced in the balanced galvanometer due to the signals were noted. The zero reading was taken on short-circuiting the tuning condenser. A loud-speaker was placed as shown at the output end of the receiver so that the signal could be heard simultaneously with the deflections produced in the balanced galvanometer placed in the anode circuit of the detector valve.

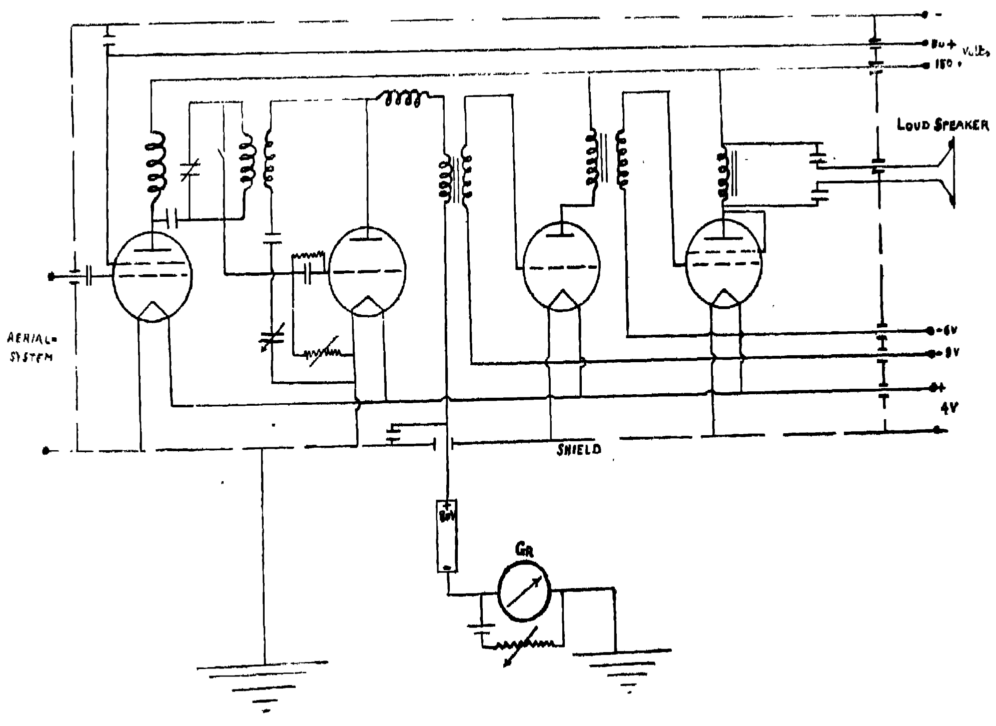

FIGURE 2

3. THEORY AND METHOD OF GROUND-WAVE SUPPRESSION

Let the down-coming wave incident at an angle i have a component of the electric force E_1 in the plane of propagation and let the electric field of the ground-wave be given by E_0. We shall denote the corresponding magnetic fields by H_1 and H_0. The angular frequency of the fields is denoted by p.

If E_L represent the e.m.f. induced by the wave in the loop-circuit of the suppressed-ground-wave system and E_A the e.m.f. in the vertical aerial, then when the ground-wave alone is present, we have

$$E_L = \alpha \frac{\partial H_0}{\partial t} = jp\beta E_0,$$

where α and β are circuit constants and $E_A = hE_0$, where h is the vertical aerial height.

Here α, β and h are all real quantities.

If Z_L and Z_A are respectively the complex impedance of the loop and the equivalent series circuit of the vertical aerial, the current in the loop circuit is given by

$$i_L = \frac{jpE_0 \left\{ \beta - \frac{Mh}{Z_A} \right\}}{Z_L + \frac{p^2M^2}{Z_A}} \quad . \qquad (1)$$

If now the value of M is adjusted so that

$$\beta = \frac{M.h}{Z_A} \quad \ldots \qquad (2)$$

the ground-wave will be completely suppressed. This condition means that the vertical aerial circuit should be tuned. Suppression is, however, independent of the tuning of the loop circuit.

The adjustements for the ground-wave suppression were made during the day when the ground-wave alone was present. The adjustments consisted in

(1) accurately tuning the vertical aerial after having disconnected the loop and also tuning the loop separately with the help of the shielded tuning condenser and in

(2) varying the mutual inductance M after restoring the original connections of the aerial system, till there was no current in the balanced galvanometer and no sound in the loud-speaker.

During the night, when the down-coming wave is present, the loop-circuit current is given by

$$i_L = \frac{2jpE_1 \left\{ \beta - \frac{Mh}{Z_A} \text{ Sin } i \right\}}{Z_L + \frac{p^2M^2}{Z_A}} \quad \ldots \qquad (3)$$

(The ground-reflection coefficient for the medium waves is taken as unity.)

Under the condition of ground-wave suppression set out in (2), *viz.*,

$$\beta = \frac{M.h}{Z_A}$$

we have, therefore,

$$i_L = \frac{2jpE_1\beta(1 - \sin i)}{Z_L + \frac{p^2M^2}{Z_A}} \tag{4}$$

Thus the value of E_1 could be determined in terms of the loop current i_L which again could be derived in terms of the deflection produced in the balanced galvanometer of the receiving set.

4. TESTS FOR GROUND-WAVE SUPPRESSION AND THE RESPONSE CURVES OF THE AERIAL SYSTEM

Tests whether a zero signal was due to a decrease of sensitivity or to the desired balancing of E_A and E_L were made as follows :

(*a*) *A further increase of M caused the signal to reappear* —

This showed that the zero was due to a balance of E_A and E_L, otherwise the signal would continually decrease with further increase of M.

(*b*) *On reversing M* with the help of a commutator arrangement x (shown in figure 1) *a relatively large signal appeared.* This was also an indication to show that the observed suppression was due to the desired balance.

The sensitivity of the suppression arrangement is shown in figure 3. The deflections of the balanced galvanometer of the receiving set were observed for the different dial readings of the vertical aerial coil. In the actual arrangement the loop coil was kept fixed and the vertical aerial coil was tilted to vary the mutual inductance between them. There was no deflection in the galvanometer when the dial reading of the vertical aerial coil was 72.

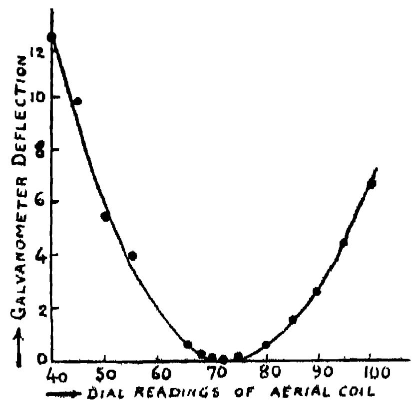

FIGURE 3

5. THE CALIBRATION OF THE RECEIVING SET AND THE CALCULATION OF THE FIELD-STRENGTH

The circuit diagram of the arrangement for calibrating the receiving set is given in figure 4. A current-attenuating-unit was devised. In this arrangement a Hull-cylinder in series with a small fixed condenser C_1 was placed in parallel with a big condenser C_2. This attenuation unit was carefully shielded and was connected as shown in the diagram with a variable condenser C and a coil L which was coupled to the coil of a neighbouring oscillator. An A.C. milliammeter was placed in the main calibration circuit and a similar milliammeter was inserted in the Hull-cylinder branch. By inducing a large current (which was measured) in the main circuit and a corresponding small current (which was also measured) in the Hull-cylinder branch, the current-attenuation-ratio was determined; or, in other words, the current through the Hull-cylinder branch was known as a definite fraction of the main current.

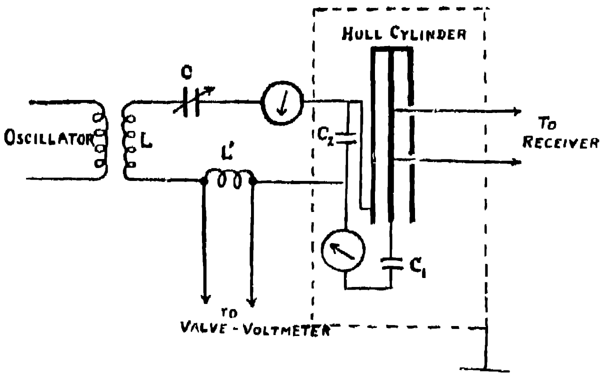

FIGURE 4

A suitable current was then induced into the calibration circuit from the neighbouring oscillator so that the voltage developed across the two tapping points (3 cm. apart) on the Hull-cylinder (from which leads were taken to the input terminals of the receiving set) was of such a value as to produce a deflection in the balanced galvanometer (G_R) of the receiving set comparable with the deflections produced by the night signals received by the suppressed ground-wave aerial system. In fact it was necessary to induce a certain range of small currents for this purpose. The corresponding currents in the Hull-cylinder branch were then evaluated. A small coil L′ was also inserted in the main circuit. Connections were taken from the two ends of this coil to the input terminals of a valve-voltmeter. The balanced galvanometer in the anode circuit of the valve-voltmeter gave perceptible deflections when small currents which did not produce any effect on the A.C. milliammeter in the main circuit were passed. From the calibration graph of the valve-voltmeter which was drawn for the purpose, the values of the small currents giving rise to these deflections in the galvanometer of the valve-voltmeter could then be obtained. The voltage-drops across the tapping points on the copper rod of the Hull-cylinder from which the leads were taken out were then determined, the inductance of the rod inside the cylinder being given by $L=\log_e \frac{R}{r}$ per cm., where R is the inner radius of the cylinder and r the outer radius of the rod.

The deflections of the balanced galvanometer (G_B) in the receiving set were then observed for a suitable range of known applied voltages and a calibration graph drawn showing these deflections for the different voltages. This calibration graph was utilised for determining the voltages induced across half the loop of the aerial system which produced the observed deflections in the receiver galvanometer (G_B) due to the constantly varying amplitudes of the down-coming wave from the ionosphere.

The field-strength of the down-coming wave was obtained from :

$$E = \frac{7\cdot6 . R_A}{A.N.f^2.L_A} .V.10^{10} \text{ volts/metre} \tag{8}$$

where N = no. of turns of the wire in the loop-aerial.

V = voltage developed across the loop.

A = area of the loop in sq. cm.

R_A = total radio frequency loss-resistance of the loop circuit in ohms.

L_A = inductance of the loop-circuit in henrys, and

f = frequency of the waves in cycles per sec.

On substituting the values of the different quantities used in the present work, the expression would reduce itself to

$$E = 1.94V. \tag{9}$$

6. EXPERIMENTAL RESULTS

Variations of the intensity of the down-coming waves

After having suppressed the ground-wave in the daytime, continuous records every half minute of the deflections of the balanced galvanometer in the receiving set connected with the aerial system were taken. Corresponding to these observed galvanometer deflections, the voltages developed across the loop were obtained from the calibration graph mentioned before. From a knowledge of the voltages, the field-strengths were then calculated with the help of (9). The variations of the field-strengths of the down-coming waves received on the nights of 10.3.39. and 11.3.39. are shown in Figure 5.

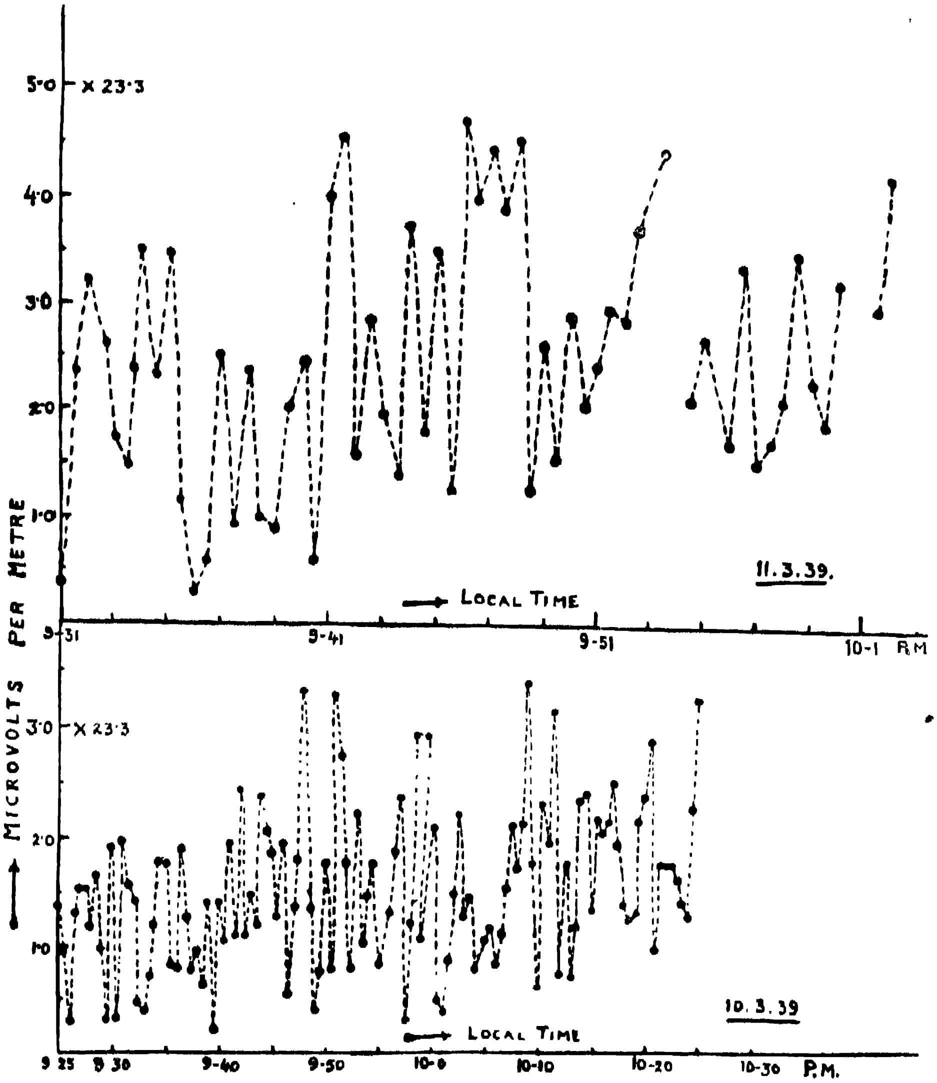

FIGURE 5

7. COMPARISON OF EXPERIMENTAL RESULTS WITH RAYLEIGH'S CALCULATIONS BASED ON RANDOM SCATTERING

If a single down-coming wave is built up of elementary contributions from a series of diffracting centres distributed more or less at random in the ionosphere, the resultant electric field would then be produced by compounding a set of components of random amplitudes and phases. Late Lord Rayleigh [4] deduced an expression for the probability of occurance of any resultant amplitude on the assumption of a large number of components of random phases. The probability is given by the expression :

$$P' = \frac{2}{R^2} \cdot e^{-\frac{r^2}{R^2}} \cdot r,$$

where R^2 is the sum of the squares of the components and $P'.dr$ is the probability of a resultant amplitude between r and $r+dr$. (Here R^2 is not known.)

The distribution of the amplitudes of the down-coming wave was found for each set of our observations and each of the distribution curves was compared with Rayleigh's distribution curve. The whole range of the observed amplitudes was accordingly divided into a number of equal parts, each part being conveniently made equal to $.8k$ where $k = 23.3 \times 10^{-6}$. The number of times the observed amplitude was found to lie between r and $r + .8k$ was then counted and a distribution curve in each case was drawn showing the number of amplitudes lying between r and $r + dr$ against the average value of r. The actual distribution curves for the two sets of observations are shown in Figure 6. In one of the curves, the most probable amplitude of the down-coming wave came out to be 1.2×23.3 or $28\mu V/\text{metre}$, whereas in the other curve the most probable value of the amplitude was 2×23.3 or $46.6\ \mu V/\text{metre}$.

In constructing the distribution curves according to Rayleigh, the following procedure was adopted :

According to Rayleigh, $$P' = \frac{2}{R^2} \cdot e^{-\frac{r^2}{R^2}} \cdot r.$$

The maximum value of P' corresponds to $R^2 = 2r_m^2$.

This can be derived by differentiating P' with respect to r and putting

$$\frac{dP'}{dr} = 0.$$

Thus $$P' = \frac{r}{r_m^2} \cdot e^{-\frac{r^2}{2r_m^2}}.$$

Here r_m is that value of r for which the number of observations is maximum. Substituting the experimental value of r_m from each distribution curve, the values of P' were calculated for various values of r. These values were afterwards multiplied by a suitable constant to give the best possible fit with each of the observed distribution curves. The computed distribution curves giving the best possible agreement with the actual distribution curves are shown by dotted lines in the same diagrams in Figure 6. It can therefore be said that the intensity variations of the down-coming wave is due largely to irregular scattering at the ionosphere.

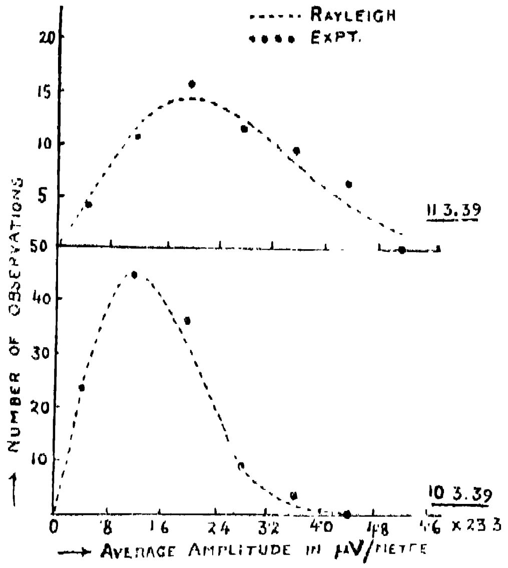

FIGURE 6

8. DETERMINATION OF THE FIELD-STRENGTH OF THE GROUND-WAVE AND OF THE RATIO OF THE VERTICAL ELECTRICAL FORCES PRODUCED BY THE DOWN-COMING WAVE AND THE GROUND-WAVE

Having obtained an estimate of the amplitude (E_1) of the down-coming wave, it was desired to obtain the value of the amplitude (E_0) of the ground-wave from the same transmitting station, so that the determination of the ratio E_1/E_0 could be possible.

The determination of the amplitude of the ground-wave was the same as the measurement of the field-strength of the Calcutta station in daytime when the ground-wave alone was present. For this measurement, observations of the deflections of the receiver galvanometer due to the day-signals from Calcutta were taken using only a loop aerial. After constructing the necessary calibration graphs, the value of the field-strength during the daytime was obtained. The mean field-strength of the ground-wave was found to be equal to 147.6 μV/metre.

Taking 28 μV/metre to be the field-strength of the down-coming wave for one set of observations on 10.3.39, $\frac{E_1}{E_0}=\frac{1}{5}$ and taking 46.6 μV/metre to be the field-strength for the other set of observations on 11.3.39., we have $\frac{E_1}{E_0}=\frac{1}{3}$. Thus, between Dacca and Calcutta, the values of the ratio of the vertical electrical forces produced by the ground-wave and the down-coming wave for these two sets of observations are 3 and 5. From the analysis of fading observations by Sengupta and Khastgir [5] this ratio has been previously found to be 3 or 4.

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